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A PROPOSED METHOD FOR INCORPORATING BALLISTIC SHOCK EFFECTS IN VULNERABILITY/LETHALITY ANALYSES

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This report describes a proposed method for modeling ballistic shock effects in vulnerability/lethality analyses. A novel approach is described which, under certain simplifying assumptions, can be implemented in a manner entirely compatible with the existing analytical environment.

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1. BACKGROUND

The problem of determining loss of armored vehicle combat utility from shock historically has taken a back seat to other problems in vulnerability science for two reasons. First, the problem is quite difficult to solve. Second, the effects of shock have been considered as secondary in their contributions to loss of combat utility to other effects such as penetration and spall. Clearly, the first reason is insignificant if the second reason is valid. The second reason is based on historical perspective which comes from a biased sample. In particular, the overwhelming majority of attacking munitions, the effects of which have been studied in live fire or other tests, have as their main defeat mechanism the perforation or attempted perforation of armor. Given this set of observations, it is not surprising that penetration and spall are the primary observed defeat mechanisms. One strongly suspects that had the majority of tests consisted of subjecting combat vehicles to dunking in water, the primary mechanism by which loss of combat utility occurred would have been observed to be water damage. The contention is, therefore, that the second reason is invalid due to its basis in a biased sample. One could also assert that most anti-combat vehicle munitions attempt to perforate armor, and so the bias is acceptable. While this may or may not track reasonably well with history, it most certainly takes the short view of the future. The "tougher armor/better bullet" race is in many instances taking a back seat to a "smarter armor/smarter bullet" race. Specifically, many armors are designed not for toughness, but rather for sophistication in the manner in which they use natural material properties to prevent perforation. At the same time, one notes a growth in interest in fast, big bullets that smash, as well as perforate.

These smart armors will distribute shock loads to the vehicle in quite a different manner than monolithic or solid layered armors. By the same token, fast, heavy bullets may use a greater portion of their total energy to impart shock to the vehicle than, say, a conventional kinetic energy (KE) round, which makes more of a "surgical incision" into the armor. Thus, one suspects that understanding and modeling shock effects will be of increasing importance to the vulnerability/lethality community. We come now to the first reason given as to why shock effects are not modeled, namely, the difficulty of the problem. In the annals of vulnerability science, the Canadian Armament Research and Development Establishment (CARDE) trials are considered as the dawn of the age of enlightenment. From the data acquired at these trials came confidence in certain vulnerability rules of thumb such as profile

hole diameter being correlated to loss of combat utility. Shock effects are less easily and naturally measured or observed, and may in fact be overlooked since they are not necessarily on or near an observed "shot line." It has been pointed out to the author that defenders of the CARDE methods would argue that shock effects are included implicitly in the profile hole diameter correlations. While this is certainly true, such implicit inclusions must be taken in the context of the type of target vehicles used in the CARDE trials. These M47 and M48 tanks were devoid of modern, sophisticated (and delicate) fire control hardware, so one would not expect shock to have been a significant contributor to the observed damage. Extrapolation to more modern systems from the CARDE data has been a point of great concern to vulnerability analysts precisely because those CARDE targets bear less and less resemblance to modern reality with each new tank that goes into production. In short, there is the potential for a good deal more shock damage in modern combat vehicles, to components which did not appear in the CARDE targets. One cannot presume the profile hole diameter correlations to retain the implicit inclusion of shock effects they once may have had. In the absence of such handy correlations between shock effects and other observed phenomena, one presumes that some sort of mathematical model is required to explain observed events. Conventional wisdom in solving shock and vibration problems is to construct a highly detailed geometric representation of the structure and model its shock transmission characteristics as accurately and with as much detail as possible. To say that this process is difficult is to make a classic understatement.

2. INTRODUCTION

In what follows is proposed a program to model shock and its effect in armored vehicles which builds on simplistic assumptions and provides for increased sophistication as knowledge and capability permit. There are three parts to the program:

(1) model the modal response of the structure of interest, and determine the significant loading parameters;

(2) determine the specific response of the structure to a specific loading function;

(3) correlate the specific response to specific loss of function.

Attempting to solve part 1 is the point at which most attempts falter, making part 2 even more difficult, thus preventing one from ever getting to part 3. Consequently, what is proposed is a simplified approach to part 1, recognizing the possible inherent inaccuracies, in order to come eventually to grips with part 3.

The fundamental simplification is to abandon (at least initially) any attempt to model a specific combat vehicle precisely and in detail by finite elements or other engineering means. Instead, it is proposed that a small set of very simple geometric shapes be modeled by finite elements; these shapes can be assembled to represent generically a large class of combat vehicles, and full- and sub-scale tests can be performed to compare with model output. For example, Figure 1 depicts a set of six shapes from which one can construct a fairly large set of "generic" combat vehicles. In Figure 2a–b are shown an Abrams Tank and a Soviet Main Battle Tank, in very simplistic form. In Figure 3a–d are shown an M113 Armored Personnel Carrier, an LAV-25, a Bradley Fighting Vehicle (BFV), and a Soviet BMP, each with considerably more fidelity than those of Figure 2, yet still quite simple. Once confidence is gained in the ability to model shock propagation in these simple, "generic" combat vehicles, details such as hatch openings can be added. While this problem is considerably easier than that of precise, detailed modeling of a specific armored combat vehicle, it is by no means simple. Perhaps conspicuous by its absence is any mention of shock effects in aircraft. While there is no reason why the methods outlined in this paper could not be applied to an airframe, they are geared more toward ground combat systems the "skin" (armored shell) of which is tough enough to transmit significant energy to components prior to its own failure. More simply stated, ballistic shock is perceived to be more of a problem in ground combat vehicles than in aircraft.

Of course, the most important questions for BRL's Vulnerability/Lethality Division (VLD) are concerned with how this simplified shock response model output relates to damage which affects combat utility, in either a generic or a specific system. Indeed, defining this relationship may be the hardest part of the entire shock problem, since there are no well-defined engineering guidelines and since the relationship between shock response and loss of combat utility is quite different from that between, say, penetrator/shot line and loss of combat utility. There are several reasons for this difference, which are important to understand if one is to make any sense at all of the ballistic shock problem.

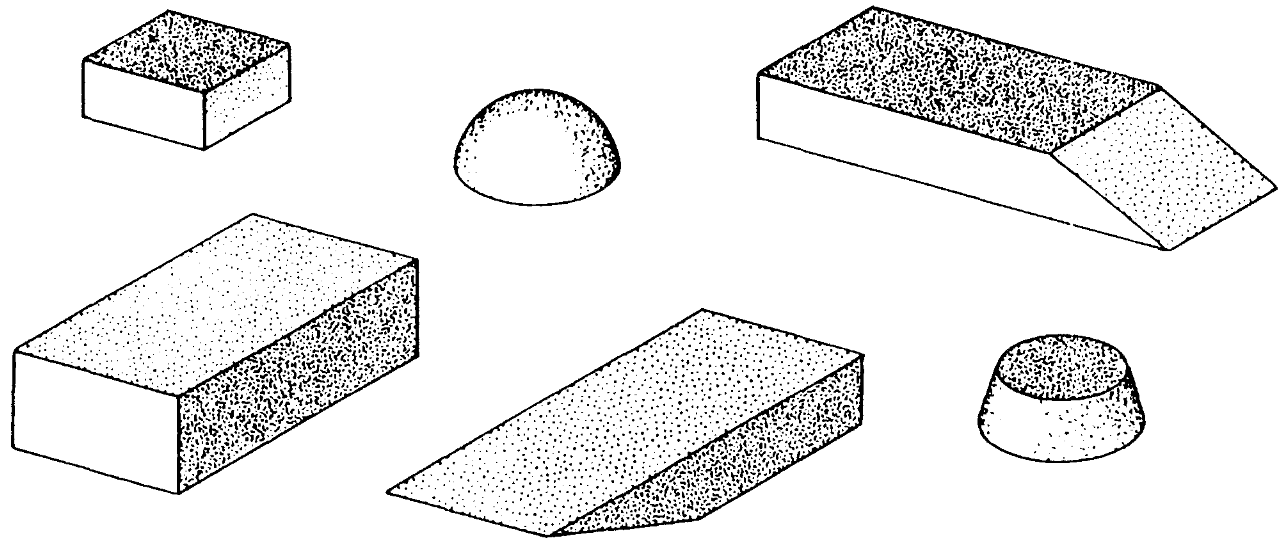
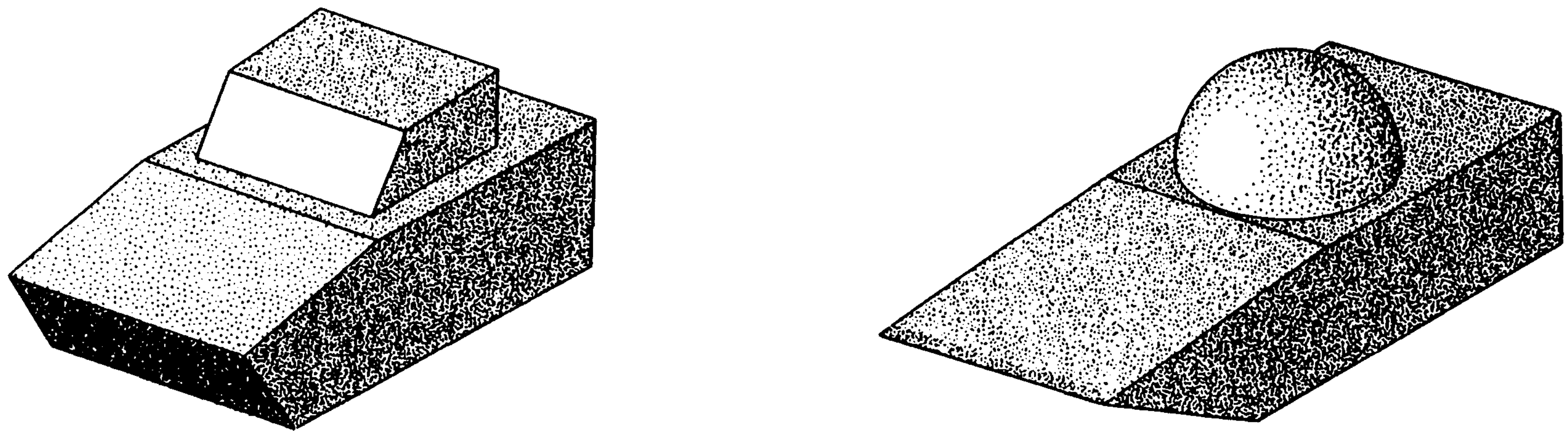


Figure 1. Basic Geometric Shapes for Generic Combat Vehicles.



(a) Abrams Tank

(b) Soviet Main Battle Tank

Figure 2. Generic Heavy Armored Vehicles.

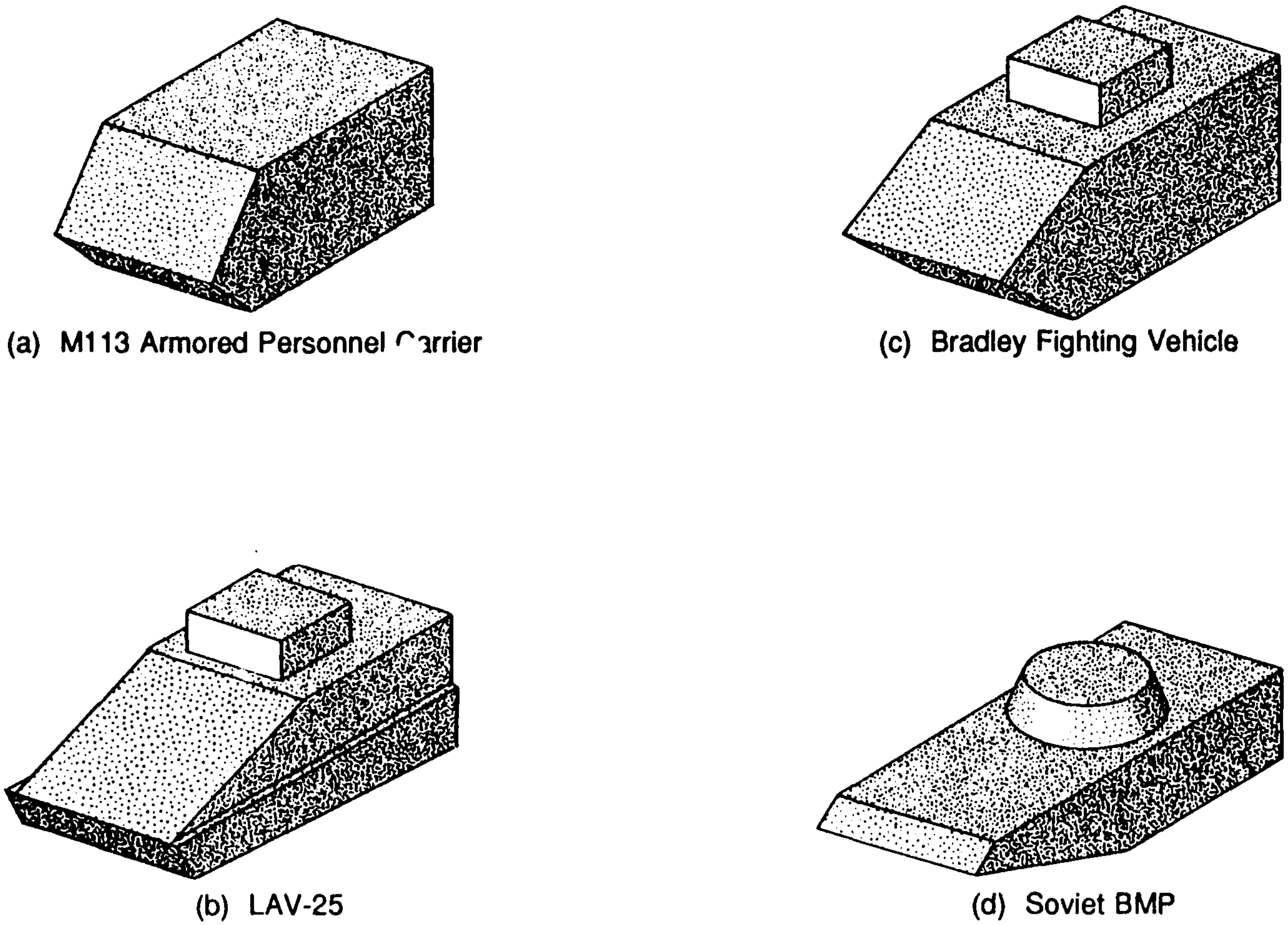


Figure 3. Generic Light Armored Vehicles.

Deitz and Ozolins (1988) have divided the vulnerability/lethality assessment process into four spaces: Space 1 is the weapon/target interaction; Space 2 is the resulting damage; Space 3 is the loss of capability (or, measure of performance space); and Space 4 is the loss of utility (or, measure of effectiveness space). Where the ballistic shock problem differs from other vulnerability/lethality problems is in the way shock maps from Space 1 to Space 2. Specifically, when a KE projectile strikes a vehicle along a specific shot line, one expects and can observe damage to be generally along and in a region about this shot line as defined by the spall cone. The current VLD analytical methods will use either a lumped- parameter or a point-burst type model and associated geometric model-querying techniques such as ray tracing to "look along" the shot line and estimate damage, producing a damage state vector in Space 2. In the case of ballistic shock, damage may occur at any point in the vehicle, perhaps far from the "shot line," if indeed a shot line even exists (which it does not in the case of attack by fuel/air explosives [FAE], for example). Moreover, shock damage may not be observable in immediate proximity to the hit; the damage in an actual test event may be neither immediately obvious nor easily located. Consider, for example, a radio which fails to function during post-shot assessment of a combat vehicle. If there are no "holes" in the radio from penetrator or spall, it is not immediately clear whether the radio has suffered internal shock damage, or whether some critical connector or electrical line elsewhere in the vehicle has been compromised (by shock, spall, fire, or other means). Shock damage also is subject to stochastic variations just as other Space 2 vector components are. One need only consider cases from personal observation of fragile items which were dropped but did not break to gain insight on this point.

It is clear, then, that shot line-type mappings from Space 1 to Space 2 are not well suited to address ballistic shock phenomena. The fundamental problem addressed by the methods proposed here is how to construct a mapping from Space 1 to Space 2. No attempt will be made to dictate how one should go from Space 2 to Space 4. Indeed, for some uses of ballistic shock modeling described in the next section, Space 2 is the correct and final analytical domain. For other uses, it may be desirable to formulate a histogram showing frequency of expected losses-of-function. But the reader should bear in mind that because the exact nature of the correlation (if it exists) between shock damage and other mechanisms is unknown, combining shock effects with others in any space higher than Space 2 is quite probably mathematically incorrect. In particular, there is no proper way to combine a

shock Pk with some other Pk. From this perspective, VLD is left with a considerable amount of effort before being able to include shock damage in routine vulnerability or lethality analyses. The remainder of this paper focuses on possible solutions to the problems cited above, and addresses the question of how accurate such analytical techniques are likely to be.

3. THE USES OF BALLISTIC SHOCK DATA

Before discussing solution techniques for the ballistic shock problem, it would be appropriate to delineate the various needs for such techniques within VLD, since the specific needs should determine the analytical approach and output. Indeed, it will be shown that the proposed solution techniques are adaptable to the broad range of applications in the Division, and that there are natural levels at which one may "tap" the process to extract required information. With this in mind, these uses are presented in ascending order of required detail, as opposed to order of priority of need.

The least technically demanding use (level 1) is in the early stages of vehicle design where considerations of size, shape, and weight are undergoing trade-off studies with operational requirements and desired capabilities. One may find, for example, that a turret of one shape is operationally equivalent to one of a different shape, but one of the two candidates provides greater inherent mitigation of shock effects because of its shape. The next most technically demanding use (level 2) is in the study of vehicle design for reduced vulnerability. Generic questions such as where best to locate fuel cells, fire control computers, sighting systems, etc., can be addressed at least in part by knowing which vehicle locations are most or least susceptible to structural deformation under shock loading. The next most technically demanding (level 3) use is for inclusion of shock effects in the total lethality of a munition. Wishing to give as much credit as possible and appropriate to an attacking munition for damage caused to a combat vehicle is a primary concern of the VLD. Similarly, noting shock sensitivity of a vehicle is an important part of vulnerability studies. Finally, the most technically demanding (level 4) use is in the design of individual components and mounts, to include crew seating and restraints, where the advantage of full knowledge of expected structural response to shock loading is clear.

It is anticipated that the proposed techniques can be used successfully to address levels 1 and 2 in the near term with medium risk, and that the third level can be successfully addressed next with medium/high risk. The question of whether the fourth level can be addressed by these techniques will in great part be determined by the amount of detail which can be incorporated into the basic structural models and the fidelity with which they capture the actual vehicle response. It must also be noted that these techniques are not likely to be useful in instances where shock effects are quite small compared to other damage mechanisms. Rather, these methods are an attempt to evaluate shock effects in the case where they are one of the major, if not the only, damage mechanism present. There are many such examples from recent live fire tests, and as the spectrum of so-called antiarmor munitions grows, there are apt to be many more such examples. As the ability to model responses of complex structures improves, so too will the ability to include smaller shock effects.

4. AN OVERVIEW OF THE PROPOSED ANALYTICAL TECHNIQUES

The exact details of how one determines the (modal) response of the generic structures in Figures 2 and 3 are not within the purview of this report, but there are a number of assumptions concerning the input to and output from such a procedure which are necessarily a part of the overall analytical effort. The basic scheme is to model the structure to determine its range of response frequencies (modes), and then to use finite element or other engineering techniques to determine the specific response at any point on the structure to a particular loading function. While easily stated, for all but the simplest of structures this scheme is difficult to implement. The sensitivity of the output of such a model to changes in the loading function will play a large role in determining the utility of that output in a vulnerability/lethality analysis. For instance, one would like the model to be able to distinguish response to a blast mine under the vehicle from response due to the impact of a KE projectile into the turret front. One suspects that the energy deposited and time duration for that deposition should be significant parameters. Given the simple generic structures posed for the problem, it is not clear that the process need be as sensitive to location of loading as it is to type of loading. It may be that no distinction has to be made between right side hull front and right side hull rear, but more can be said about this once a model is operational.

In terms of output, the expectation for the response model is that given a loading function, one should be able to plot response vs time at any of the first few modes of vibration for any given point on the structure. It might also be desirable to have output in the form of color-coded graphics, so one could note the locations of maximum (amplitude) response. Such output would be especially useful for basic design studies (levels 1 and 2), where one could determine those vehicle locations at which to avoid placing shock sensitive items or perhaps recommend a less shock sensitive structural shape.

The next step in shock analysis, once the response of the generic structure to a specific loading function at a specific point has been computed, is to identify within the actual combat vehicle those components which are both critical to vehicle function and likely to be sensitive to the anticipated shock levels. There is clearly a good deal of subjectivity (perhaps one should say engineering insight and vulnerability/lethality analysis experience) in such an identification process, but for a tank one would immediately list each crew member and any components containing glass associated with vision and/or fire control. Actual test data would dictate additions to this list for specific red or blue systems, but the basic task is to establish "where to look" for shock damage. There should be no expectations that the analyst will be able to identify all shock-sensitive components in advance, nor should it be anticipated that every shock-sensitive component is critical to vehicle mission. For example, a radio mounting bolt broken by shock will not necessarily keep the radio from functioning. Once these "significant" components have been identified, their locations in the actual vehicle (that is, the points in the actual vehicle to which each of these components is attached) must be mapped to a corresponding location in the generic structure for which the shock response has been computed. While specific (x,y,z) coordinate mappings are not likely to be possible, if the generic shapes have been appropriately scaled then reasonable locale mappings, perhaps using computer overlays of the actual target description with the generic structure, can be made. At this stage of the analysis, one could get an indication of whether the component identified as being susceptible to shock was actually subjected (or rather, had its attachment point actually subjected) to any structural deformation, and at what level. It should be noted that the term structural deformation refers to any possible combination of transient motion and permanent bending/breaking.

The next step in the process (to address uses in upper level 2 and beyond) is to analyze the response of the component given the motion of its mount or attachment point. In certain rare (quite probably nonexistent) instances, one may have the luxury of a detailed study of mount/component responses for a given system, and perhaps even extensive shock testing of components. Such data are especially unlikely for red systems, and the expense of such testing on blue systems is prohibitive. While there have been extensive tests done on Abrams tank components, the author believes these tests were a onetime offering, never to be repeated. This means, of course, that analysis must be used in lieu of testing, although there has been a good deal of structural response data recorded during live fire and other tests. What is suggested here is that one presume that "a driver's seat is pretty much the same" in terms of how it passes shock along to the passenger no matter which vehicle it's in. Certainly, the angle the driver makes with the horizontal axis of the vehicle contributes to the severity of any vertical accelerations to which this member of the crew is subjected, but resolution of vector components is not an overly taxing matter. There are a number of criteria (GADD Severity Index, Head Injury Criterion, etc.) which have been developed over the years to deal with levels of incapacitation once the acceleration levels are known.

A similar analysis of inert components such as those containing glass is less straightforward, but can be simplified if certain assumptions are made. The most basic of these concerns the question of which frequencies cause the greatest damage (or possibly, are most often the cause of damage)—the high modes or the low modes. A word of caution—a low mode of vibration for a small object could be a "high" frequency on some absolute scale, while a low mode of vibration for a large structure could be at quite a "low" frequency on that same scale. The point of this discussion is that the structural model based on the simplified assumptions suggested in this report will have its greatest fidelity to the actual vehicle in the lower modes of vibration. These lower modes are in fact the frequencies which have the most energy associated with them. Given these facts, one must make an analysis of component response based on what can happen to the component when subjected to what for it may be relatively low frequencies with perhaps significant amounts of energy contained in them. That damage can occur at relatively low frequencies has many common examples, but the following will illustrate the point nicely. In a rather well-known television commercial, a singer hit an appropriate high-frequency note and a glass shattered. Now, one could also break the glass by subjecting it to its own first mode of vibration (a low frequency), that is,

simply bend it. Simple torque will also work—twisting the stem until it breaks. If our analysis shows that the component will fail at a relatively low frequency, the question of whether it also would have failed due to high frequency content of the same loading function is moot. Clearly, what such analysis will fail to detect is failure of components through relatively high frequencies beyond the range of the structural model. A more relevant example might be the case of a driver's hatch in a tank which opens as a result of a munition impact. The hatch may function perfectly after the test event, and there may be no signs of permanent structural deformation in the vicinity of the hatch. The explanation would be that transient (low-frequency) shock-induced bending of the surrounding structure was sufficient to release the hatch. No "damage" is observable, and accelerometers in the vicinity of the hatch are unlikely to have recorded the low-frequency culprit. This last point is important, because it suggests, intentionally, that shock data previously collected was biased toward the higher frequencies and may therefore not provide full information. One of the advantages of the velocity gage developed by Walton (1989) at the Combat Systems Test Activity, Aberdeen Proving Ground, MD, is that it has the potential to record reliably structural response at frequencies lower than accelerometers.

The discussion in the previous paragraph is central to the entire concept of shock modeling. The extent to which one can rely on low modes to represent shock transmission through the structure is directly related to the level of detail required in the finite element or structural engineering model. The concept outlined above is one with which there is likely to be a great deal of disagreement; it represents a departure from conventional wisdom on the subject of ballistic shock, which is to seek a high degree of detailed structural fidelity in the model. One cannot treat propagation of high frequencies without a highly detailed model, so the two go hand in hand. It is important to understand the nature of what is being proposed here. First, it is not intended that high frequencies be disregarded, nor is it proposed that there should never be a high-resolution model to work from for ballistic shock analysis. What is important is that the problem is approached in a building-block fashion. Having a highly detailed finite element model of some combat vehicle is great, but possessing that model is to understanding ballistic shock as having one entry from a table of logarithms is to understanding the log function. Specifically, even if one could do a complete and accurate ballistic shock analysis (by luck or by intelligence) using this detailed finite element model, how does that help study ballistic shock effects in, say, something like a future Soviet tank?

It doesn't, unless one understands the basic principles behind shock propagation and damage.

As a second point, this concerning high vs low frequencies, one must be very careful about the interpretation and use of two parameters—loading function and energy dissipation. The high-frequency, high-energy components are, it is true, produced by short-duration loads such as that from a shaped-charge jet. But the greatest shock damage to an armored vehicle will be that induced by the impact of the warhead/flight body on the vehicle, and while the jet is short duration, warhead impact is of considerably longer duration. The nigh frequencies induced by a shaped charge jet or even a KE penetrator are dissipated rapidly in the nonlinear stresses local to the point of impact. Large massive structures such as cast turrets or heavy armors are excellent low-pass energy filters; the more linear, globally transmitted shock has more energy in the lower frequencies. The saving feature about the method proposed in this report is that it is a milestone along the path to the highest possible fidelity of shock modeling, and as such can be evaluated and accepted or rejected with minimal perturbation to the long-term research work.

There are additional factors which favor a low-detail, low-frequency approach to the problem of component shock damage. First, while a comprehensive shock testing program on components is highly desirable, it is also cost prohibitive, in both dollars and equipment. There simply are not enough Abrams fire control computers in the world to perform all of the shock, spall fragment, and penetration testing to characterize totally their vulnerability, and still maintain an operational fleet. One must make do with partial testing, analysis, and good old-fashioned engineering judgement. Further, any method for predicting ballistic shock effects which relies heavily on component testing will be of limited use in studies of future U.S. systems, whose components are not yet defined, and in foreign future and present systems. In short, if the approach to the shock problem relies on highly detailed testing and analysis, the general problem remains unsolvable.

If one accepts (or at least fails to reject immediately) the concept that low-frequency (and "low" is still relative) shock damage is important to study, then it turns out that several other simplifications fall nicely into place. First and foremost of these is the question of how shock is transmitted from the vehicle structure to a component through its mount. For the most part,

shock mounting of components is done to protect them from the high-frequency content of normal road shock and vibration as simulated on shaker tables; the lower frequencies are not generally compensated for except by the suspension system, which changes them rather than removing them. Because the mass of any component is much less than the mass of the turret or hull to which it is attached, low frequency motion of the component will be virtually identical to the motion of its attachment point. That is, analysis of shock damage by the methods proposed here will not require extensive information about component mounting; one may assume that the component will undergo the same motion at the same (low) frequencies as the basic vehicle structure. While there may be some phase delay, especially where crew are concerned, amplitudes should not differ significantly. It is also possible, as will be discussed further on in this report, to mitigate the effects of the lack of detailed knowledge about component and mount responses by using Monte-Carlo techniques.

With all these assumptions in place, one can look toward a general method of assessment and/or analysis. By superimposing a color-coded generic vehicle shape on the full computer target description and thus identifying areas/components for further study, the target description query problem is resolved. By using the existing database of accelerometer and velocity gage information together with damage assessment records and component testing already accomplished, it should be a relatively straightforward process to develop, for each system of interest, a list of shock-sensitive critical components. From the same existing data, rules of thumb relating shock levels to component damage can be formulated. These rules are envisioned as step functions relating the states killed/not killed to some parameter such as maximum amplitude in the response curve in each of the first five modes. The final output of a shock damage analysis will be a Space 2 shock damage state vector, with binary vector components. This vector must then be combined with damage state vectors from other mechanisms (spall, penetrator, etc.) to produce a final Space 2 vector. The process of combining these vectors is certainly nontrivial unless there is true phenomenological independence, which is at best doubtful. Nevertheless, use of the inclusive-or seems quite appropriate. That is, anything damaged by shock or penetrator or spall should be included in the damage state vector as being damaged; no extra credit is given for anything damaged by more than one mechanism, and of course no credit is given for anything not damaged by any mechanism.

From the Space 2 damage vector, one can proceed along any of the variety of paths available to vulnerability analysts, from Standard Damage Assessment List (SDAL)/Damage Assessment List (DAL) Pk computation (Zeller and Armendt 1987) to degraded states (Starks 1988). It is important to reiterate that the proposed process does not recommend computation of a "shock Pk" to combine with some other Pk. To do so would put a far more severe strain on mathematical credibility than the inclusive-or process. Moreover, as Starks has so eloquently pointed out (Starks 1988), computation of quantities like a shock Pk tends to destroy the audit trail, and brings repeatability of results into serious question. Finally, a binary-type damage state vector is more readily and directly compared with field trials. That the software tools to perform such analyses can be developed in a manner consistent with current techniques (Hanes et al., to be published) within the VLD is not in doubt. By divorcing the shock analysis from both the lumped-parameter and the point-burst models, while retaining the same type of operating environment and damage state vector output, the greatest level of analytical flexibility is retained. Moreover, the purpose of the present work is essentially a first cut at a mapping from Space 1 to Space 2. As knowledge increases, a more complete analytical framework may evolve.

Reference has already been made to the stochastic nature of shock propagation and effects. The VLD has long recognized the propriety of stochastic methods of analysis (Ozolins 1988). The proposed shock analysis methods described here lend themselves naturally to the accommodation of Monte-Carlo techniques. For example, for the initial loading on the finite element structural model, one could vary parameters such as location, duration, impact velocity, and mass (assuming a sensitivity analysis reveals these to be significant). One could further vary structural stiffnesses and material properties within the bounds of measurement, production variations, and so on. In this manner, the structural response model would produce a distribution of possible responses, together with some estimate of the likelihood of any particular response occurring. From this point in the analysis, one could introduce further stochasticism by varying, for example, the amplitude of the shock levels to which crew are subjected, simulating cushioned or spring-mounted seats. It is entirely possible that the shock response of certain components could be so well characterized that fail/no fail probability distributions could be determined for given shock levels. The result of such Monte-Carlo trials would be a set of possible shock damage state vectors, just as current vulnerability/lethality methods produce distributions of possible penetrator and spall damage

vectors. A potentially significant benefit of stochastic component response modeling is that it could take the place, at least initially, of detailed knowledge about mount/component shock response and interaction. As knowledge increases, the Monte-Carlo parameters can be refined, but one should be skeptical of any thoughts that stochasticism can be replaced by determinism in this process.

Finally, to address the questions of accuracy and growth potential, it should be clear that no restrictions are placed on either of these by the proposed methods. The more accurate and realistic the response model becomes, the easier it will be to superimpose it on the geometric description of the actual target. Similarly, the more that is known about component shock response, the more refined the "rules of thumb" or component shock failure algorithms can be made. A final word about simplified geometric structures. Remember that for basic vehicle design concept studies, one needs to work with those simple structures—fine detail doesn't exist at that stage. But even if such detail is available, adding it to the model at the beginning may lead to other difficulties. If the loading history cannot be "appropriately characterized," (that is, characterized to the same level of detail as the finite element model) or, if damage criteria are not sufficiently sophisticated (detailed), fidelity of results may be lost. It is far too easy to stop work on a problem in its tracks by falling into the trap of having detail in one part outrun the detail in other parts, and then proclaiming that "just as soon as we can get as much detail into all the other input as we have in the model, we can do the problem." One should not expect precise quantification of ballistic shock from the methods proposed here, but simple models and simplified input and simplified assumptions should provide both a solid starting point and internally consistent qualitative results. Ultimately, the accuracy of this type of analysis, as in all vulnerability/lethality analyses, will be gauged by the degree to which the distribution of shock damage state vectors reflects reality as it is perceived by the user.

5. SUMMARY AND CONCLUSIONS

A general framework has been described by which ballistic shock effects on combat vehicles may be incorporated into vulnerability/lethality analyses. Based on certain simplifying assumptions and the incorporation of Monte-Carlo techniques, it has been argued that seeking a high level of detail may unnecessarily complicate the problem. It has been shown that the proposed methods fit readily into both degraded states-type analyses and more traditional

SDAL/DAL techniques. Moreover, these methods are independent of the conventional compartment, point-burst, cr stochastic point-burst models, yet can be compatible in a Modular Unix-Based Vulnerability Estimation Suite (MUVES) environment with these codes. Finally, these methods are entirely consistent with increased knowledge of or level of detail in structural response computations, as well as with increased sophistication in vulnerability/lethality analyses.

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